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The calculation of the resonant sound reduction index for use in EN12354

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Summary

The application of the EN12354 prediction method to lightweight building constructions which typically have critical frequencies in or above the frequency range of interest requires the estimation of the resonant sound reduction index. Since the resonant sound reduction index can not be directly measured, the value must be estimated from measured data or calculated theoretically. Several methods of estimating the resonant sound reduction index have been evaluated. An alternative method of calculating the flanking sound reduction index as proposed by Villot and Guigou-Carter has also been evaluated. The evaluation was conducted by comparing the predicted flanking sound reduction indices which were calculated using the different methods of calculating the resonant sound reduction index to the measured flanking intensity sound reduction index for several different lightweight building element constructions. The constructions included single, homogeneous elements as well as double leaf elements. The alternative method of predicting the flanking sound reduction index as proposed by Villot and Guigou-Carter is recommended.

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1. Introduction

One of the difficulties in applying the EN12354 (ISO 15712-1) [1, 2] method of predicting the flanking sound reduction index to lightweight building elements is that lightweight building elements typically have critical frequencies in or above the frequency range of interest. In the derivation of the EN12354 method, it was assumed that only resonant transmission through the junction is important for the prediction of the flanking sound reduction index [3]. Therefore, the resonant component of the sound reduction index must be estimated for the EN12354 method to be applied to lightweight building constructions.

The EN12354 method calculates the flanking sound reduction index R_{ij} according to:

$$\mathrm{R}_{ij,EN12354} = \frac{R_{R,i}+R_{R,j}}{2} + \frac{D_{R,ij}+D_{R,ji}}{2} + 10\log\left(\frac{S_o}{\sqrt{S_i S_j}}\right) \quad (1)$$

where R_R is the resonant component of the sound reduction index, $D_{R,ij}$ is the mechanically excited velocity level difference between elements i and j, S_i and S_j are the areas of elements i and j, respectively and S_o is a reference area.

The resonant sound reduction index R_R is an immeasurable quantity that must be either calculated theoretically or estimated from measurement data. There have been a number of different methods of estimating R_R proposed in the literature (see for example [4]). However, calculations using the different methods can result in a wide range of values, none of which can be directly evaluated using measurement data. One of the objectives of the COST Action FP0702 [5] has been the adaptation of the EN12354 so that it can be reliably applied to timber based, lightweight constructions. A result of the Action is that the number of methods of determining R_R under consideration has been reduced to three.

The objective of the study described in this paper was to evaluate the methods of determining R_R which have been proposed by the COST Action. Since the true best estimate of R_R can not be determined directly, the accuracy of the different

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methods of determining R_R were evaluated by comparing the measured flanking sound reduction index of different lightweight building elements to the values of the flanking sound reduction index predicted by the EN12354 method using the different methods of determining R_R.

2. Calculation Methods Evaluated

2.1. Method Gerretsen

The premise of Method Gerretsen is that the calculated non-resonant sound reduction index can be subtracted from the total, measured sound reduction index, resulting in an estimation of the resonant sound reduction index such that [6]:

If $\left[1-\left(10^{\frac{-R_T}{10}}\right)2\sigma_{NR}\left(\frac{2\rho_o c_o}{2\pi f \rho_s}\right)^2\right] > 0.1$ then

$$R_{R,Gerretsen} = R_T - 10\log\left[1-\left(10^{\frac{-R_T}{10}}\right)2\sigma_{NR}\left(\frac{2\rho_o c_o}{2\pi f \rho_s}\right)^2\right] \quad (2)$$

else

$$R_{R,Gerretsen} = R_T + 10 \quad (3)$$

where R_T is the total, measured sound reduction index measured in the laboratory, σ_{NR} is the non-resonant component of the radiation efficiency, ρ_o is the density of air, c_o is the speed of sound in air, f is the frequency in Hz and ρ_s is the mass per unit area of the element.

The limit for the calculation of $R_{R,Gerretsen}$ shown in Equation (3) was required because the use of Equation (2) without the limit can lead to values for $R_{R,Gerretsen}$ which can not be calculated.

2.2. Calculated Input Data Method

A correction factor which is based on the equations found in Annex B of EN12354-1 is [4]:

$$R_{R,CID} = R_T + 10\log\left[1+\frac{2\sigma_{NR}}{\sigma_R^2}\frac{(l_1^2+l_2^2)}{(l_1+l_2)^2}\eta_{tot}\sqrt{\frac{f}{f_c}}\right] \quad (4)$$

where l_1 and l_2 are the dimensions of the element where l_1 is the largest dimension, η_{tot} is the total loss factor of the element, σ_R is the resonant radiation efficiency measured when an element is excited with mechanical excitation and f_c is the critical frequency of the element.

2.3. CSTB Correction Factor

A correction factor proposed by Villot and Guigou-Carter [7] which is based on the radiation efficiencies of the element is:

$$R_{R,CSTB} = R_T + 10\log\left(\frac{\sigma_T}{\sigma_R}\right) \quad (5)$$

where σ_T is the total, airborne radiation efficiency which includes both the resonant and the non-resonant components and is measured when an element is excited with airborne noise.

2.4. CSTB Method

An alternative approach to calculating the flanking sound reduction index has been proposed by Villot and Guigou-Carter [7, 8]. The flanking sound reduction index according to this CSTB Method is:

$$R_{ij,CSTB} = \frac{R_{T,i}+R_{T,j}}{2} + \frac{D_{a,ij}+D_{a,ji}}{2} - 5\log\left[\frac{\sigma_{R,i}\sigma_{R,j}}{\sigma_{T,i}\sigma_{T,j}}\frac{S_i S_j}{S_o}\right] \quad (6)$$

where $D_{a,ij}$ is the airborne excited velocity level difference between elements i and j. The CSTB Method differs from the method of EN12354 in that the calculation of the resonant sound reduction index is not required, the airborne excited velocity level difference is used instead of the mechanically excited velocity level difference and the total, airborne radiation efficiency is used.

3. Measurements

3.1. Measured Values

The evaluation was made using L shaped constructions which were created by joining two panels at one edge. Panel i of the L shaped panel was mounted into an opening between a reverberant room and a semi-anechoic room. The flanking intensity sound reduction index of the L shaped panels was measured using sound intensity according to ISO15186-2 [9].

The velocity level differences of the L shaped panels were measured *in situ* in accordance with ISO 10848-1 [10]. The mechanically excited velocity level difference between the elements $D_{R,ij}$ was measured using a mechanical shaker as an excitation source according to Section 7.2 of ISO 10848-1. The airborne excited velocity level difference $D_{a,ij}$ was measured using airborne noise to excite panel i according to Section 7.4 of ISO 10848-1. The loss factors of the elements were measured *in situ* according to ISO 10848-1.

The resonant radiation efficiency σ_R of each of the elements was measured *in situ* by exciting element

Table I. List of the smaller L-shaped panels used for the evaluation

Elements	Leaf Material	Stud Material	Construction	Element thickness (m)
Single Panel	1.6 mm Steel	-	Panels spot welded to angle iron	0.002
Single Panel	4 mm MDF	-	Panels glued and screwed to a 1"x1" wood bar	0.004
Double Leaf Panel	10mm gypsum board	Metal	Studs crimped. Gypsum board screwed to studs.	0.091
Double Leaf Panel	4 mm MDF	Wood	Studs nailed. MDF glued and screwed to studs.	0.078

i and then measuring the time and spatially averaged velocity and the sound intensity of panel j. In the case of the single leaf panels, this method of exciting the panels avoided the extra point force radiation contribution from the shaker. The airborne diffuse field excited radiation efficiency σ_T was measured by installing identical, single elements into the opening between the reverberation room and the semi-anechoic room and measuring the sound intensity and the time and space averaged mean squared normal velocity on the receiving room side.

3.2. Evaluated Lightweight Elements

Two different size L panels were evaluated. In each case, two identical, lightweight elements were joined together at one end to form the L shaped panels. The first size panels were 1.548m x 0.948m. A list of the lightweight materials used for these panels is shown in Table I. The second size panel was constructed of double leaf 13mm gypsum board screwed to 50 mm x 100 mm wood studs spaced at 600 mm. Panel i had an area of 11.52 m^2 and panel j had an area of 7.87 m^2.

4. Calculations

The flanking sound reduction indices of the L shaped panels were predicted according to EN12354 using the different methods of calculating the resonant component of the sound reduction index. The velocity level difference used for the calculations was for one direction only rather than the direction averaged velocity level difference. Although the EN12354 method requires the velocity level difference to be direction averaged, the potentially large differences in the velocity level difference in each transmission direction can increase the uncertainty of the predictions. Therefore, this source of uncertainty was removed from the evaluation by considering one transmission direction only.

The radiation efficiency terms used for the calculation of Method Gerretsen and the Calculated Input Data Method were those given in Annex B of EN12354. Although there are other formulas for calculating the radiation efficiency terms, it seemed reasonable to assume that a person calculating the apparent sound reduction index using EN12354 would use on the equations presented in the standard. In addition, the CSTB Correction Factor was calculated using the values of σ_R and σ_T calculated according to the proposed revisions to the EN12354 standard [11]. This comparison was made to compare the measured values of σ_R and σ_T and those predicted using the equations of Annex B.

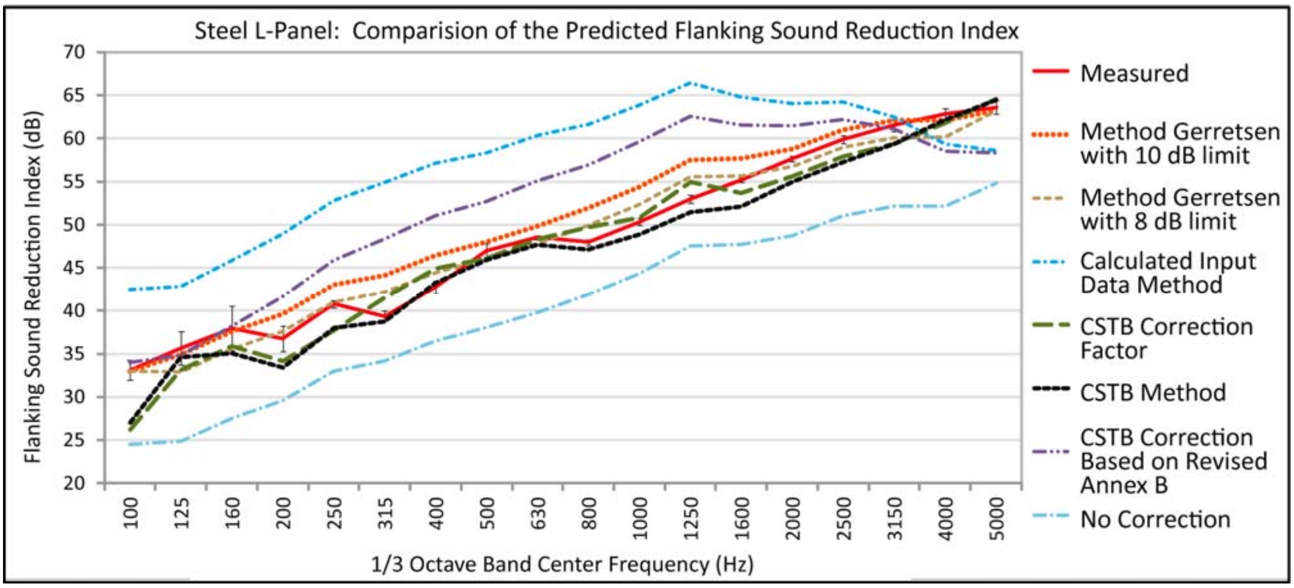

Figure 1. Comparison of the R_{ij} for the steel L-panel. The critical frequency f_c was in the 8000 Hz 1/3 octave band.

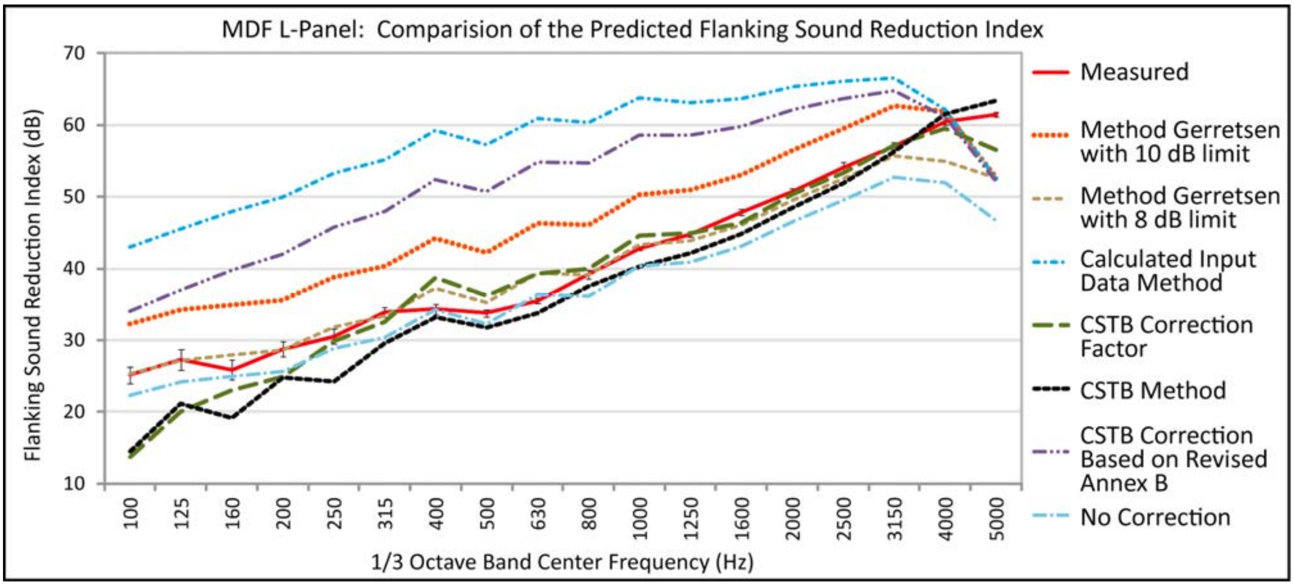

Figure 2. Comparison of the R_{ij} for the MDF L-panel. The critical frequency was in the 8000 Hz 1/3 octave band.

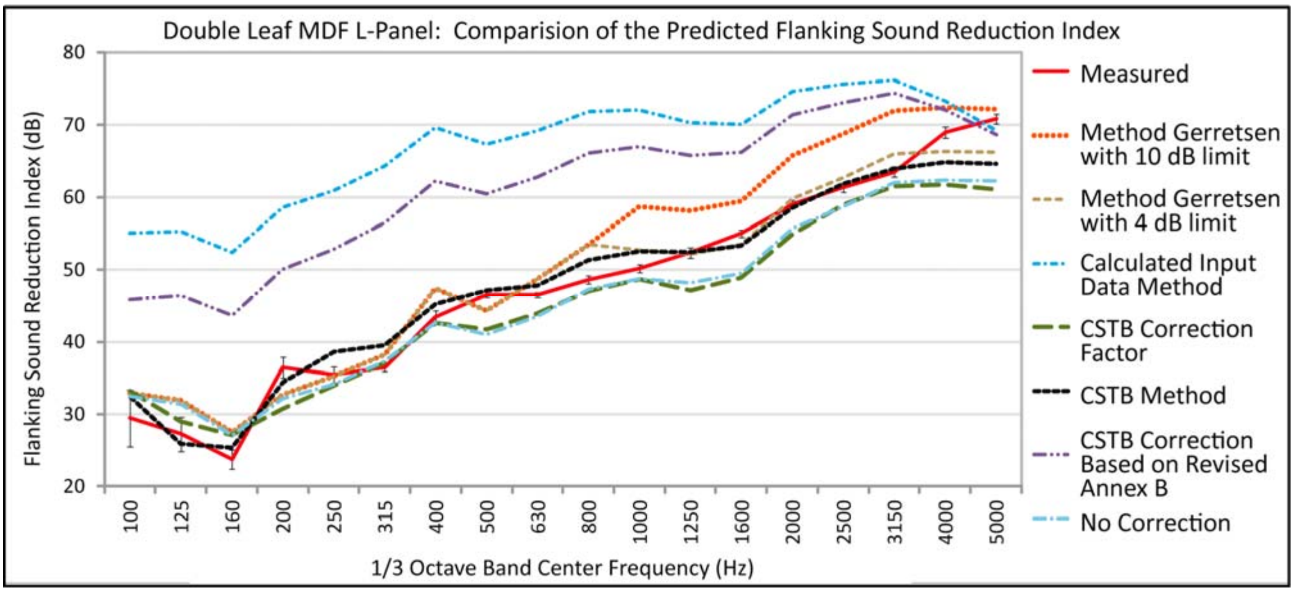

Figure 3. Comparison of the R_{ij} for the double leaf MDF L-panel with f_c in the 8000 Hz 1/3 octave band.

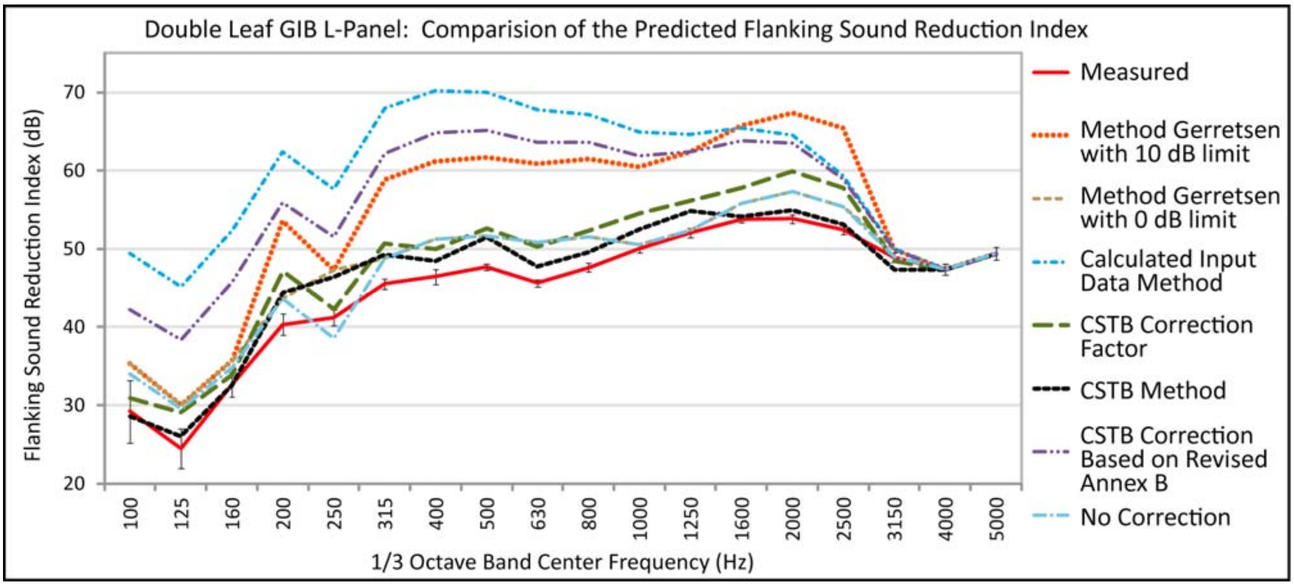

Figure 4. Comparison of the R_{ij} for the double leaf GIB L-panel with f_c in the 4000 Hz 1/3 octave band.

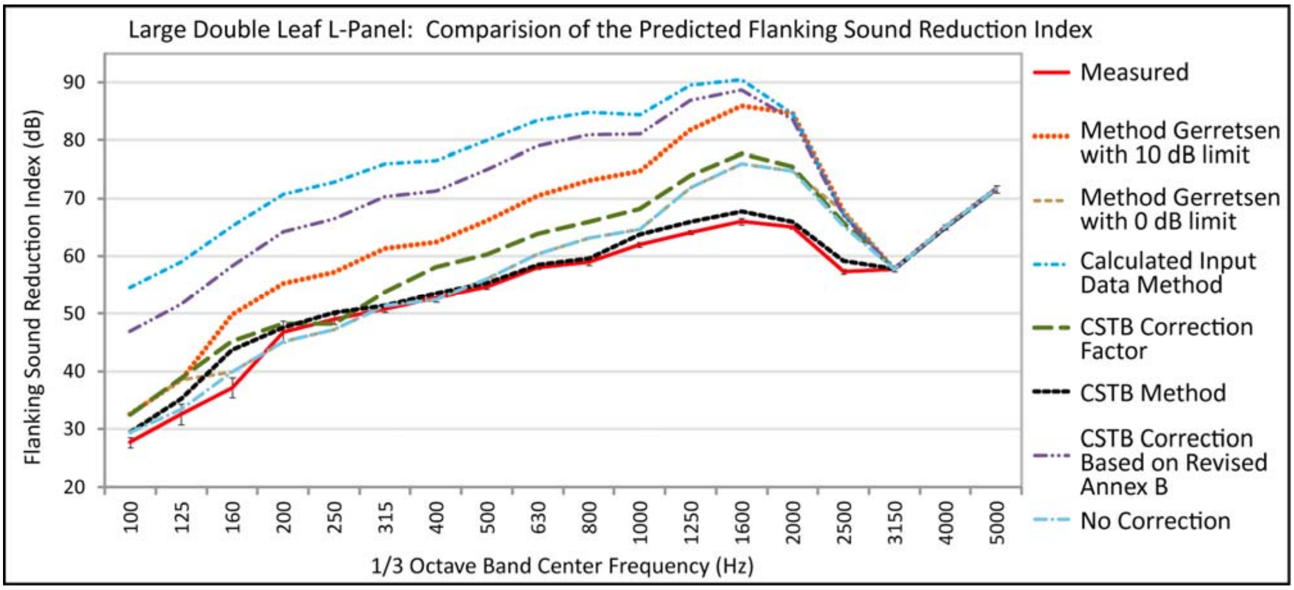

Figure 5. Comparison of the R_{ij} for the large double leaf GIB L-panel with f_c in the 3150 Hz 1/3 octave band.

5. Results

The measured and predicted flanking sound reduction indices of the lightweight, L-shaped panels are compared in Figures 1-5. The error bars in the figure are the 95% confidence interval based on the standard deviation of repeatability of the measurements calculated according to GUM [12].

Each plot shows the result of using Method Gerretsen both with a 10 dB limit according to Equation (3) and with a limit which was found to better fit the measured value of R_{ij}. The CSTB correction factor is shown using both the measured values of σ_R and σ_T and those predicted according to the revised Annex B. The plots also show the prediction of R_{ij} if the measured sound reduction index of the elements was used in the EN12354 method without a correction for the resonant component.

6. Discussion

Overall, the best prediction of R_{ij} was that using the CSTB method. The CSTB method predicted R_{ij} with an average maximum deviation of 6 dB from the measured value. The CSTB method has an advantage over the EN12354 method in that the value of R_R does not need to be determined and since both of the radiation efficiency terms used in the correction factor are measureable quantities.

The use of the Calculated Input Data Method using the radiation efficiencies calculated according to Annex B systematically over predicted the value of the flanking sound reduction index in excess of 25 dB for all of the panels with the exception of the steel panel where the over prediction was by 15 dB. The results of this study have shown that the Calculated Input Data Method should not be used to estimate the resonant sound reduction index.

The use of Method Gerretsen with the 10 dB limit tended to over predict the value of R_{ij} which is a concern. In the case of the large GIB panel, the over prediction was up to 20 dB. Smaller limits on the correction on the order of 0 dB to 4 dB are shown in the figures to result in more accurate estimates of R_{ij} for the double leaf constructions. However, in the case of the small and large double leaf GIB panels, even the use of a 0 dB correction led to an overestimation of the value of R_{ij} in many of the 1/3 octave bands.

The use of the CSTB correction factor based on the measured values of σ_T and σ_R resulted in the best EN12354 prediction of R_{ij} for the lightweight elements evaluated in this study. The use of the CSTB correction factor with the EN12354 method is similar to using the CSTB method with the exception of using $D_{v,ij}$ instead of $D_{a,ij}$. The EN12354 method, assumes that only resonant transmission through the junction is important for the prediction of the R_{ij}. However, the better accuracy of the predictions using the CSTB Method compared to the predictions using the EN12354 method with the CSTB Correction Factor suggest that the structure-borne noise transmitted through the junction due to the non-resonant excitation of the panel in the source room should be considered. The figures show that this was especially the case for the double-leaf elements which are typical of lightweight building constructions.

The EN12354 prediction using the CSTB Correction Factor based on measured radiation efficiencies was on average within 4 dB of the measured R_{ij} whereas the CSTB Correction Factor based on the radiation efficiencies predicted using Annex B of the revised EN12354 consistently over predicted R_{ij}. The difference between the predictions using the measured and the calculated radiation efficiencies suggests that there are errors in the equations of Annex B and highlights the difficulty of calculating the radiation efficiencies theoretically. It was to avoid this problem that Gerretsen cleverly removed the radiation efficiency terms from the EN12354 calculations by assuming reciprocity between the transmission directions. However, unlike R_R, the values of σ_T and σ_R can be measured directly so that theoretical predictions of the terms can be improved by comparing the predictions to the experimental results. Therefore, better models for the prediction of σ_T and σ_R can be developed with the goal of eventually eliminating the need to measure the values experimentally.

The use of the measured sound reduction index without a correction R_T is shown in the figures to underestimate R_{ij} for all of the panels with the exception of the large and small double leaf GIB panels. In the case of the double leaf GIB panels, using R_T resulted in a better prediction than using any of the estimated resonant sound reduction indices. However, the use of R_T in the EN12354 method was not as accurate as the use of the CSTB method at predicting R_{ij}.

7. Conclusions

The use of the formulas for calculating the radiation efficiencies found in the current or the proposed EN12354 should not be used in any of the correction factors to determine the resonant sound reduction index. The use of the Calculated Input Method was shown to significantly overestimate the flanking sound reduction index and therefore is not recommended. Method Gerretsen with the 10 dB limit was found to over predict the resonant sound reduction index. A smaller limit in the range of 4 dB to 0 dB may result in more accurate predictions for double leaf constructions, but even with the smaller limit the flanking sound reduction index can be over predicted. The CSTB Correction Factor based on measured radiation efficiencies was found to be the best method of calculating the resonant found reduction index for the panels evaluated. However the best results were achieved by using the CSTB Method with measured radiation efficiencies and the measured airborne excited velocity level difference.

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